Section Life Cycle Management

Working Groups

International Expert Group on Life Cycle Assessment for Integrated Waste Management

Terry Coleman[1]*, Paolo Masoni[2], Allan Dryer[3] and Forbes McDougall[4]

[1] UK Environment Agency • [2] ENEA, Italy • [3] Scottish Environmental Protection Agency • [4] Procter & Gamble

*** Corresponding author:** Terry Coleman, Waste Strategy Manager, UK Environment Agency, Block 1 – Government Offices, Burghill Road, Westbury-on-Trym, Bristol, BS10 6BF, UK (terry.coleman@environment-agency.gov.uk) (http://www.ieglca.org)

1 Introducing the Expert Group

The objective of sustainable waste management is to deal with society's waste in a way that is environmentally efficient, economically affordable and socially acceptable. To assess such sustainability, tools are needed which can predict the likely overall environmental burdens of any waste management system. Life Cycle Assessment (LCA) can be applied to waste management systems to assess their overall environmental burdens. The concept of Integrated Waste Management (IWM) combines waste streams, waste collection, treatment and disposal methods, with the objective of achieving environmental benefits, economic optimisation and societal acceptability. LCA tools applied to IWM systems can support the development of truly sustainable waste management systems.

In general, LCA practitioners have been very much focused on the methods and the issues surrounding product life cycle development. There is now also considerable interest in the application of LCA to whole waste management systems rather than the specific waste management process used to treat a single product. The results of this area of research lead to the optimisation of complete waste management systems, which treat municipal solid waste.

A forum was established in April 1998, in London, UK to support the development of LCA techniques specifically for IWM systems. There are now approximately 30 members from 10 countries (Australia, Canada, France, Germany, Ireland, Italy, Netherlands, Sweden, UK, USA) who regularly attend meetings. Membership of the group is by invitation.

Objective. The objective of the forum is 'More sustainable waste and resource management through the appropriate use of life cycle techniques'.

Actions. The main focus areas for the group members are:

1. to reach agreement on the way that major technical issues are dealt with for the application of lifecycle tools for integrated waste management
2. developing and improving models and tools for integrated waste management processes
3. identifying data gaps, research needs and scope for collaboration exchanging information on R & D projects and life cycle work in waste management
4. improving the communication of the uncertainties and the presentation of results for use by various audiences.

Technical issues. The technical issues specific to LCA for IWM systems, which are currently being addressed by the group, include (but are not limited to):

- Functional unit
- Waste Classification and changes to composition and quantity of household waste
- Recording Energy
- Avoided burdens/offset credits
- Carbon balances in waste management systems
- Inventory data used for LCA for IWM
- Temporal and spatial problems of applying a life cycle approach to landfilling and composting: Comparison of modeling approaches
- Allocation: advantages and disadvantages of different approaches
- Uncertainty analysis
- Key parameters on sensitivity analysis
- Presentation of results

The following two chapters present two technical guidance notes which address the issues of the definition of the Functional Unit for a LCA for waste management and a clarification of the difference between Product versus Waste LCAs. – For further information see http://www.ieglca.org

2 The Functional Unit and Reference Flow in Waste Management Studies

Terry Coleman, Bernie Thomas
(UK Environment Agency, Westbury-on-Trym, Bristol BS10 6BF)

2.1 Introduction

Life cycle assessment (LCA) has been much maligned and criticised for being biased and producing the results that favour the interests of those who commissioned the study. It is however, the studies themselves that are faulty and those carrying them out that are at fault.

The rules and procedures within LCA are set out in an international standard, ISO 14041. Following these should ensure that any study produces results which fairly reflect the goal and scope that were set for the study. Peer review and publication in accordance with ISO14040 should ensure that the goal and scope are not deliberately biased.

A key part of the goal and scope of an LCA is the selection of the functional unit. For a waste management LCA, the functional unit describes the primary function(s) fulfilled by the waste management system. (and indicates how much of the function is to be considered in the LCA study}.

2.2 Definition of the functional unit

The Functional Unit is the basis for selecting one or more systems to evaluate what might provide this function. The functional unit is defined in ISO 14041, which states: "In defining

the scope of the LCA study, a clear statement on the specifications of the function of the product [system] shall be made...The functional unit defines the quantification of these identified functions – considered within the goal and scope of the study". The Functional Unit must be clearly defined and measurable in all dimensions. That is, each aspect of the function that can vary and might affect the results needs to be quantified.

2.3 The functional unit for waste management

The functional unit in a waste management study can be a given amount of waste e.g. 100,000 tonnes or the amount of waste produced by the subjects of the study in a given time. In the case of municipal solid waste (MSW) the latter would be the amount of waste produced by the population of the district, region or municipality being studied. In other cases, for example, a life cycle study comparing end-of-life tyres, it may be an average tyre, the average from a particular manufacturer or the total amount of tyres produced in one year from vehicles of a particular type in a given geographic region. In every case, a study will require additional knowledge to define a meaningful function for the system, select a functional unit and to produce accurate inventory data.

In a waste management study, in common with general life cycle studies, the results of inventory and therefore the functional unit are intimately linked to the composition of the material which is the subject of the study. However, unlike many product studies where a single manufactured item is involved, even a single component waste stream will usually be made up from many different waste products. Apart from certain simple waste streams, waste is almost always a mixture of different components comprising different materials. To be effective and yield meaningful results, any life cycle study of waste and its management needs to include:

1. the components that are present in the waste and their proportions
2. knowledge of the components of the waste stream being studied
3. the way these interact with all the waste management processes under consideration – that is everything that is produced as a result of applying the process and
4. how much of this waste is produced by a given population over a given time frame.

(1) The components present and their proportions

Solid waste streams are often subject to component analysis. For Municipal solid waste, this analysis is now tending towards standard components, such as paper, card, glass, food waste, garden (green) waste, aluminium, plastics, etc.

Each of these components of municipal solid waste will present different opportunities for its management and contribute differently to the impacts resulting from different forms of management. Thus paper could be recycled, digested, landfilled or incinerated. If paper is landfilled or digested, the biological carbon in it will produce methane (a powerful greenhouse gas) and carbon dioxide. A proportion of this could be recovered and could be burnt to produce useful energy. When paper is incinerated, again the biological carbon within it will give out heart and a proportion of this energy can be recovered. Recycling paper – i.e. using recycled paper to replace wood pulp in the manufacture of paper, will significantly reduce the energy demanded for manufacturing one tonne of paper, but this process will also produce residues that must be treated and disposed of appropriately.

Therefore, if you want to better manage the amount of paper in the waste stream you need to know how much paper is potentially available for recycling, how much methane would be produced in a landfill, etc.

(2) Knowledge of the components of the waste stream being studied

As explained above, all components of the waste stream will have different impacts when managed in different ways. Therefore, when considering their potential life cycle impacts, we must know both their macro- and micro-constituents, which requires analysis of each component. Macro-constituents are those which form the major part of the component and whose presence will cause us to recognise it. Thus for paper, we need to know the amount of carbon (biodegradable and non-biodegradable), oxygen, hydrogen, nitrogen, iron, etc.

However, the weight of any constituent is not the only guide to the significance of its effects. Some substances are present only at very low levels and yet may still be of significance in the consideration of the results and the options for managing waste, where there could potentially be released to the water environment in landfill leachate, from recycling and composting or emitted into the atmosphere by incineration. These are often subject to specific limits because of their known (mainly human) toxicity, e.g. cadmium, mercury, chromium and dioxins.

(3) The interaction of each component with all the waste management processes under consideration

Once the composition of each component is known in terms of its constituents, this knowledge together with knowledge of the effect of each waste management process on the component needs to be combined. This is necessary in order to model the effects of each process on every component to determine the nature of the different substances produced and the amounts to each of the environmental media (air, land and water).

For example, a proportion of the biodegradable carbon content in paper or in green waste will degrade in the anaerobic conditions of a digester or a landfill to produce methane and carbon dioxide. Some of the carbon will be in the form of 'woody' material, eg lignin and this may remain as a solid in the landfill or in the out put from the digester. However, the same waste in an incinerator will produce only carbon dioxide and a small percentage of carbon. The amount of energy produced from a given amount of waste from burning this methane or from burning the paper will vary according to the proportion of paper in the waste and this could materially affect the results of any study. These and similar considerations will need to be understood and modelled for all components and all potential waste management processes.

(4) How much waste is produced by a given population over a given time frame?

Different populations with different lifestyles and levels of economic well-being produce different amounts of municipal solid waste of different compositions. Such differences can be at least as important as differences in waste management technologies and energy generation to the results of a study. For MSW, both

the quantity and composition will depend on the number and nature of the population producing the waste being studied.

What does this mean for the functional unit? In carrying out a life cycle study of a municipal waste management system for an area, it is possible to define the functional unit as either unit weight (e.g. one tonne) of average waste or the total weight of waste of a given composition. It is also possible to define the functional unit in terms of managing the amount of waste produced by the average person or average household or in terms managing the total amount of waste produced by the population in the area. All of these are equally acceptable, the key factor is that however the functional unit is defined, the relationship between the population and the amount and composition of the waste produced will be required to complete the study.

The reference flow. In addition to the functional unit, any LCA study will need a reference flow which is used to calculate the inputs and outputs of the system. Data on flows will almost inevitably come from different sources for the various parts of the system being studied. These data sets are almost certain to be based on different reference flows from that chosen for the waste management study and each value that is required will have to be adjusted to the new reference flow.

There is no rule on what reference flow should be chosen. Adjustments between different datasets are generally made by commercially available software packages or using spreadsheet software, so the calculation is not the issue. However, it is important that results are able to be compared with expected values by eye and so reference flows tend to be unitary or a simple number.

The reference flow can be the same as the functional unit – it makes no difference to the study. If, for instance, the latter has been chosen as the management of an average tonne of waste, then it is quite likely that both the reference flow and the functional unit will be the same.

Consideration of additional functions. At its simplest, waste management is the removal of mixed waste from the household by municipality to a single place of management – either landfill or incineration. All the waste under consideration is managed this way, greatly simplifying the modelling and compositional considerations.

However, present (and moreover planned) integrated municipal waste management systems will rarely be so simple. They will generally include multiple pick ups of different materials and delivery by members of the household of wastes to specific collection points. Some of these materials will be used to produce energy and others (through recycling or composting) will be used to replace virgin materials.

Where some of these components substitute for others, either by materials or energy, it is possible to ascribe more than one function to the system – so the functional unit might be to manage one tonne of waste and to produce a certain amount of electricity, 100 kilograms of glass, 100 kilograms of newspapers, and 50 kilograms of compost. Including these as additional functional units of the (waste management) system is carried out by using an additive systems approach – where additional systems are added to each system. Where the waste management system cannot provide these functions, 'theoretical' systems to do this are added. This is viewed as more technically correct but is generally more difficult [for waste managers] to understand than the relatively simple consideration of looking at credits to the waste management system because of different levels of off-set burdens[1].

In practice, when applying life cycle techniques to determine the impacts associated with municipal waste strategies, as with any other life cycle study, the functional unit should reflect the function to be provided by the system. Where systems are being compared, as is normally the case, there should be functional equivalence between them. If the additional functions of any of the systems are not taken into account in the comparison then these omissions or the additional benefits not included should be clearly documented.

Constraints on the functional unit. Depending on the purpose of the study, it may or may not be sensible to impose constraints on the systems being considered and potentially therefore on the functional unit.

Where there is absolute freedom in terms of the waste management strategies to be considered, then any practical strategy, or mix of option is possible. Where there are external constraints, such as limits on the amount of waste to landfill, or a targeted amount to be recycled, or internal constraints, such as the requirement to incinerate a certain amount of waste, then it makes sense only to consider and compare options which meet these criteria.

It is therefore considered preferable to compare systems on the basis of managing a fixed quantity of waste, where each of the various systems delivers within the statutory limits and at or above the required targets. The calculation must include the benefits produced in each system from replacing virgin materials or energy production.

3 Relationship between using LCI for Products and using LCI for Integrated Solid Waste Management

Peter White, Forbes R. McDougall
(Procter & Gamble, Newcastle upon Tyne, NE12 9TS, UK)

3.1 Introduction

This document distinguishes between applying Life Cycle Inventory (LCI) to product/package lifecycles, and applying it to integrated solid waste management systems. These represent two different uses of LCI tools, with different potential user groups. Product designers and manufacturers can use LCI tools to help optimise the life cycles of individual products or packages. Solid waste managers can use LCI to help optimise integrated solid waste management systems. If both tools are used, the result should be an overall environmental optimisation.

3.2 Life Cycle Inventory tools for individual products and packages

Most early LCI tools and studies have looked at the life cycles of individual products or packages. The functional unit for such LCIs is normally defined in terms of providing the function of the product (e.g. the washing of clothes), or in the case of packaging, it is

[1] An off-set burden is the burden credited to the system being studied by replacing a virgin raw material with one extracted from waste. It amounts to all of the upstream burdens from the point that the recycled waste replaces the virgin material. Against these credits must be set the additional burdens associated with the collection, separation, cleaning and transportation of the recycled material and the burdens associated with its processing.

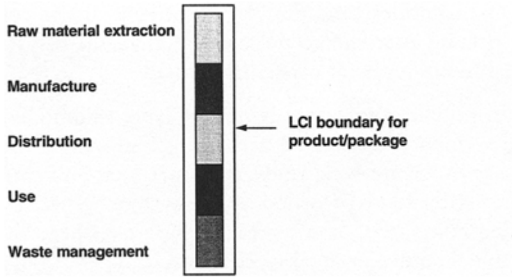

Fig. 1: Boundary of the life cycle inventory for a product or package

usually defined as delivering a certain weight or volume of product to the consumer. The boundary of such LCIs includes the whole lifecycle of the specific product, from raw material extraction, through manufacture, distribution, and use to post-use waste management (with possible recovery/recycling) (**Fig. 1**).

3.3 Life Cycle Inventory tools for solid waste management

Since the functional unit of an LCI actually specifies the function that a product system provides, it is also possible to apply LCI to services such as solid waste management. In this case, the functional unit is "the management of the solid waste from a given specified region". The life cycle of solid waste runs from the moment that the material becomes waste (i.e. when it ceases to have value), through the treatment processes in the solid waste system until the material ceases to be waste, by becoming an emission to air or water, inert material in a landfill, or by becoming a useful product again through a valorisation process. The boundary for this LCI application is shown in **Fig. 2**.

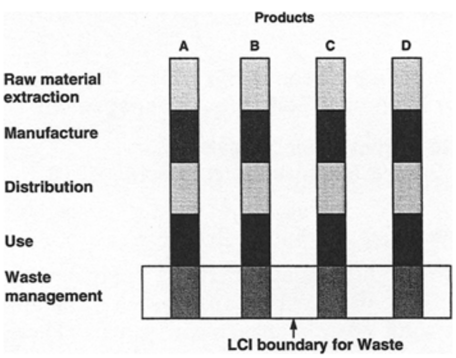

Fig. 2: Boundary for a life cycle inventory of solid waste

Clearly there are overlaps between the two approaches, since the LCI for a product includes the time the particular product spends in the waste management system, and the LCI for waste includes the waste management stages of all products and packages. There are fundamental differences, however, since the two applications have different functional units, and therefore different uses (and potential users). A product LCI can be used to optimise a specific product life cycle, normally within a given infrastructure system (energy generation system, transport system, solid waste management system, etc.). A solid waste LCI, in contrast, aims to optimise the infrastructure system for managing a given amount and composition of waste. In a solid waste LCI all life cycle stages prior to the product becoming waste can be omitted if they are common to all the subsequent waste management options. But, if the waste LCI does consider recycling, credits for the avoided environmental burdens of virgin material production should be given. In this case the waste LCI needs to take into account the relevant stages of the subsequent

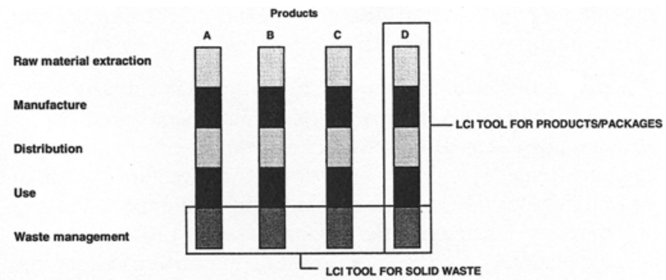

Fig. 3: A practical approach to environmental optimisation. Designers and manufacturers optimise performance of products and packages (vertical analysis), whilst waste managers, municipalities and policy makers optimise integrated waste management systems (horizontal analysis)

recycled_product also. Hence product LCIs are of use to those that can control product design and manufacture; solid waste LCIs are of use to those that plan or manage solid waste management systems. They represent two different tools for two different user groups (Fig. 3).

3.4 Choosing the right tool for the job

It is important that this distinction is appreciated, since different questions relating to product and waste management will require the choice of the appropriate tool. For example, a solid waste LCI (the horizontal approach) attempts to assess the environmental burdens of the waste, once produced. Since it takes the solid waste as a given (the zero burden approach), this method cannot be used to assess how waste prevention can best be achieved, since this occurs prior to the creation of waste. It can look at the consequences of changes in waste composition, which may arise through waste prevention measures, on the waste management system, but cannot identify how and where waste prevention should occur. Since each product system will be different, the opportunities for waste prevention must be identified on a product-by-product basis, through the use of product LCIs (the vertical approach). Therefore, comparisons of product systems, such as re-usable versus one-way packaging systems, need to be done using a product LCI, on a product-by-product basis.

In contrast, comparisons between treating a given waste by recycling, composting, energy from waste or landfilling, and how to achieve the optimal combination of such options in an integrated solid waste management system, can be achieved using a solid waste LCI (horizontal approach). All life cycle stages prior to the product becoming waste can be omitted if they are common to all the subsequent waste management options.

3.5 Sustainable Solid Waste Management

There are two general requirements for more sustainable solid waste management:

(1) the production of less waste in the first instance and
(2) an environmentally effective, economically efficient and socially acceptable way to deal with the solid waste that is still produced.

LCI tools can help in both of these areas. LCI tools for products can help identify where waste prevention can occur, on a product-by-product basis. An LCI tool for solid waste can then be used to determine the most effective integrated waste management system to deal with the remaining solid waste (see Fig. 3).

Reference

McDougall F, White P, Franke M, Hindle P (2001): Integrated Solid Waste Management: A Lifecycle Inventory. 2nd Edition. Pub. Blackwell Science Ltd